

2N2484—SILICON PLANAR TRANSISTOR WITH VERY HIGH GAIN AT LOW I_C AND WITH LOW NOISE

The new Fairchild 2N2484 is a silicon planar transistor with high Beta at very low currents. This is particularly advantageous in the design of operational amplifiers where the highest possible gain for a given collector current is desirable because the correction current supplied by the stabilizing system is inversely proportional to the Beta of the first transistor. Operation of differential pairs is also improved by using the 2N2484 as lower current for a given gain reduces drift due to differential dissipation. These transistors are available in matched pairs with dual packaging (Fairchild Special Products) which further improves stability and balance. Typical dual type numbers are the SP8413A and SP8414A.

The 2N2484 has very low noise figures especially at low currents and/or high impedances. Choice of this transistor for use in either wide- or narrow-band amplifiers should be based upon the current and impedance levels to be used. Figure 1 shows the approximate demarcation between the

TWICE ACTUAL SIZE
TO-18



operating areas at 10 Kc for types 2N2484 and the 2N2049 (a typical low-noise planar transistor made by Fairchild having larger geometry construction). At other frequencies, the same relationship exists.

The 2N2484 also offers the possibility of unusual circuit designs. One example is the multi-vibrator with a 1 to 10^6 frequency range which is described with schematic on page 4. Others are . . . photo-emissive cell amplifiers, transducer amplifiers—sonic and ultrasonic, and instrument applications such as the low noise preamplifier in a transistor NF tester (described in APP-50). In addition to the above, it also might be used where minimum power is a criterion such as in satellite and space vehicles; thus, microwatt switching can be added to the list of 2N2484 applications.

CHARACTERISTICS

The 2N2484 specifications stress microampere current levels:

h_{FE} at 1.0 μA is greater than 30 and h_{FE} at 10 μA is from 100 to 500.

Gain-bandwidth product at 50 μA is greater than 15 Mc and at 500 μA is greater than 60 Mc.

Also, capacitances are very low — C_{ob} and C_{TE} are 6.0 pf max. at 5 V (V_{CB}) and 0.5 V (V_{EB}) respec-

tively; and designs will not be limited by collector voltage — $LV_{CEO} = 60$ V.

The 2N2484's excellent low-noise characteristics versus frequency are shown in Fig. 2. At a collector current of 10 μA and an R_s of 10 K, it has a typical noise figure of 1.8 db for either wide- or narrow-band measurement. Low noise figure designs are made easier by the full data sheet information including constant NF curves versus I_C and R_s .

Fig. 1. OPTIMUM OPERATING AREAS

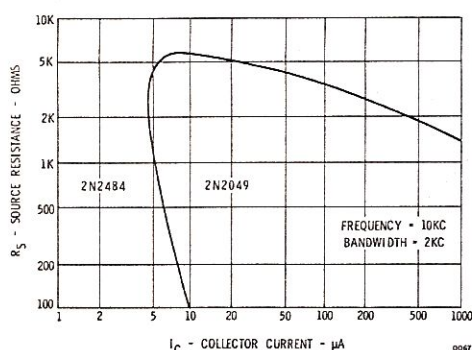
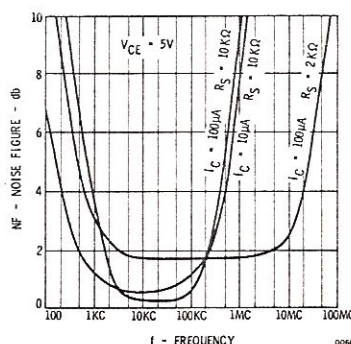


Fig. 2. NF vs. FREQUENCY



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2N2484 (continued)

TYPICAL APPLICATIONS

Wideband, High Input Impedance Amplifier—The circuit shown in Fig. 3 was constructed to demonstrate 2N2484 performance. Measurements showed improvement over that for other planar transistors in the same circuit... input impedance was 1.2 megohms up to 3 Kc, spot noise figure was 1.6 db at 1 Kc with a source resistance of 300 kilohms and its voltage gain of 20 db was essentially flat from 10 cps to 50 Kc.

Microwatt Switching Circuits—The 2N2484 can switch better at microampere currents than is possible with other standard transistors. One suggested type of circuitry is "All Transistor Logic" (TTL). TTL is described in Fairchild Semiconductor Application Note APP-49. A seven-stage ring oscillator was constructed with the 2N2484 for both switches and gates to measure the average propagation delay time of each stage for a range of microampere currents. The circuit and measurements are shown in Fig. 4. In TTL the delay of the transistor gates is very low because the collector and base currents switch alternately from the base junction thus maintaining a base charge at all times.

The 2N2484 is recommended for almost all applications operating at currents of less than about 1 mA in addition to higher current levels applications requiring very high gain.

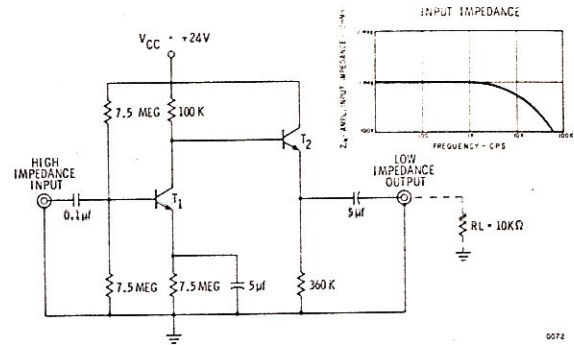


Fig. 3. High impedance wideband amplifier using 2N2484's.

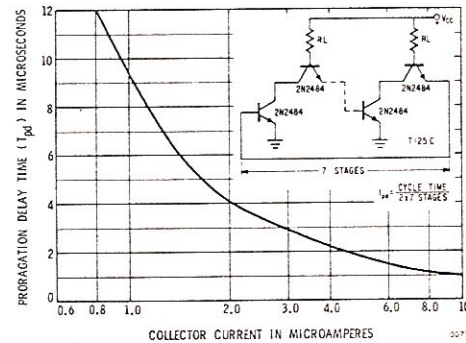


Fig. 4. Measurement of 2N2484 propagation delay time.

CONVENTIONAL AND NON-CONVENTIONAL THERMAL RESISTANCE RATINGS OF SILICON PLANAR TRANSISTORS

Conventional data sheet ratings for power dissipation, P_D , and thermal resistance, Θ_J , are applicable to continuous Class A or d-c operation only. In power pulse operation dissipation characteristics within short time periods vary considerably between different transistor structures and materials. Thermal conditions in both of these areas will be discussed.

Operating with excessive junction temperature, whether continuous pulse operation or accidental surges, should be avoided. The effects may be immediate catastrophic failure or a long period of gradual deterioration.

Excessive current or power, usually accidental in nature, can cause an open or short. For instance, several amperes of current can vaporize the gold-alloy wire used for the base and emitter leads which may have a size of about 1 mil in high frequency transistors. Figure 1 shows a transistor where the base lead melted completely and the particles (white spots in photo) were attracted to the emitter by the high potential.



Fig. 1. Accidental catastrophic transistor failure due to current in the order of amperes.

Thermal Resistance (continued)

However, the effect of operating diffused silicon transistors at excessive junction temperatures is not always immediately apparent especially if the voltage is limited to less than breakdown and/or the current is limited to a reasonable value. Continued operation over maximum ratings gradually deteriorates the transistor's parameters often causing circuit inoperation or even transistor destruction. For instance, to show the effects of extreme conditions, a sample of high reliability transistors, having a proven failure rate of 0.004% per 1000 hours with 60% confidence level, was placed on life test at over twice their power rating. After 10,000 hours, a gradual deterioration of I_{CBO} resulted in thermal run-away on 40% of the units, and h_{FE} had degraded 50% on the survivors. For this reason, Fairchild semiconductor recommends that the factory be consulted on designs in which operation over ratings is desired.

The normal mode of operation used for conventional ratings by the manufacturer is shown as region II of Fig. 2. These same ratings can be applied to region I where the collector-base junction is in saturation. They are not always applicable to region III, the avalanche mode. It has been shown¹ that the thermal resistance increases with avalanche when there is a finite impedance between the emitter and base terminals. Under this condition, the current is "pinched-in" under the emitter and current density increases causing thermal resistance to rise. In a like manner, double-diffused transistors operating in a common-base circuit at collector voltages in excess of LV_{CEO} have higher thermal resistance.²

The maximum allowable dissipation for continuous operation at any set of conditions is easily determined since:

$$T_J = T_A + \Theta P$$

where T_J = transistor junction temperature;
 T_A = ambient temperature; Θ = thermal resistance; P = power dissipation.

The maximum allowable value of T_J and the value of Θ , for a specified case temperature or in free air, are assigned by the manufacturer. The power dissipation in the transistor for continuous operation can be calculated from:

$$P = V_{CB}I_C + V_{BE}I_B = V_{CE}I_C + V_{BE}I_B$$

Generally the value of $V_{BE}I_B$ is small and can be neglected.

For silicon diffused transistors in pulse operation the instantaneous power dissipation can exceed the continuous power rating without harmful effects if the maximum junction temperature during the ON pulse is known to be less than maximum rating. This is useful where it is desired to operate nonsaturating switching circuits to maximum capability. In this case, knowledge of the

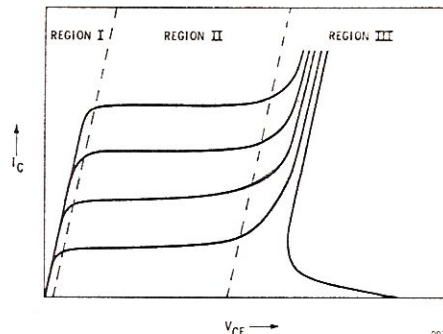


Fig. 2. Operating areas of a transistor.

thermal response characteristics of the transistor is necessary for conservative designs. These conditions cannot be generalized but both thermal resistance and thermal response can be measured by using one of the temperature sensitive parameters of the transistor.

For silicon diffused transistors, measurement of the forward voltage of the base-emitter diode, V_{BE} , appears to give the most accurate results. The other temperature sensitive parameters that may be considered have drawbacks — I_{CBO} is too low for accuracy, V_{BC} requires that the collector junction be forward biased before measurement with rapid cooling in the switching interval on HF transistors, and h_{FE} is relatively insensitive to temperature on certain types of devices.

Measurement of thermal resistance is carried out in two steps. First, the relationship between V_{BE} and temperature, dV_{BE}/dT , must be determined. Second, the thermal resistance can be calculated by measuring dV_{BE}/dP and applying the measured dV_{BE}/dT against the first relationship. Thermal response can be determined in a third step by measuring the change in base-emitter voltage with time, dV_{BE}/dt .

Refer to Fairchild Application Note APP-53 for detailed measurement techniques and for the application of the thermal response characteristics.

REFERENCES:

1. R. H. Beeson, I. Haas, and V. H. Grinich, "Thermal Response of Transistors in the Avalanche Mode," National Electronics Conference, October, 1959. (Fairchild Technical Paper TP-16.)
2. H. B. Grutchfield, "The Effect of Collector Voltage on the Thermal Resistance of a Transistor," Fairchild Semiconductor Application Note APP-54.

UNIQUE MULTIVIBRATOR—VARIABLE FROM SECONDS TO MICROSECONDS USES 2N2484 TRANSISTORS

Multivibrators using two transistors can be made adjustable over a two decade frequency range by varying the resistances of the time constant networks. Greater ranges are difficult because they are limited by the minimum and maximum currents over which the transistors will operate—the maximum base current by the recharge time and the minimum current by the ratio: $I_B = I_C (\text{sat}) / \beta$.

The unusual circuit described here can be designed to have a very much wider range; and by using the recently introduced Fairchild 2N2484, a 1 to 10^6 frequency ratio is possible. The 2N2484 transistor has an extremely high gain at microampere currents.

Two methods are used to extend the frequency range beyond the conventional circuit capability—the β_0 is increased by connecting the 2N2484's in a Darlington configuration, and the charging or timing current is switched to avoid excessive hold-on current and to facilitate the use of a single charging-current source.

CIRCUIT DESCRIPTION

The circuit is composed of two compound Darlington's— Q_1, Q_2, Q_3 and Q_8, Q_9, Q_{10} ; two charge-current switching transistors— Q_5 and Q_6 ; and two capacitor-charging emitter-followers for risetime improvement— Q_4 and Q_7 .

The two sides of the oscillator are identical and one side operates as follows: In the Darlington, the PNP 2N996 transistor furnishes a feedback emitter-follower arrangement and additional Beta to the two NPN types. Q_3 also maintains conduction when the charging current is removed as its collector current is derived from Q_1 whose collector, in turn, supplies base current to Q_3 .

When the Q_1, Q_2, Q_3 Darlington is conducting, Q_5 's base voltage is such that it turns-on. At the same time Q_6 is reverse biased because the Q_8, Q_9, Q_{10} Darlington is turned-off by the negative potential provided by C_1 's finite charging rate. In this condition Q_5 will supply C_1 with the discharging current necessary to bring the Q_8, Q_9, Q_{10} Darlington back to conduction.

The minimum charging current required to maintain oscillation is dependent upon both R_1 and Q_3 . Q_3 provides positive feedback in the loop of Q_3, Q_1 , and Q_2 and the threshold of instability arrives when Q_3 starts to supply collector current to the base of Q_1 initiating regeneration. This threshold current, I_T , has the minimum value $I_T (\text{min}) = V_{EB} (Q_3) / R_1$ where I_T is also dependent upon minimum I_B and gain from the relation $I_T = \beta_{Q_1} \beta_{Q_2} I_B (\text{min}) (Q_1)$.

The best combination for the longest reliable symmetrical periods is when the minimum charging current, $I_B (\text{min})$, is at least ten times I_{CO} plus I_{EBO} of

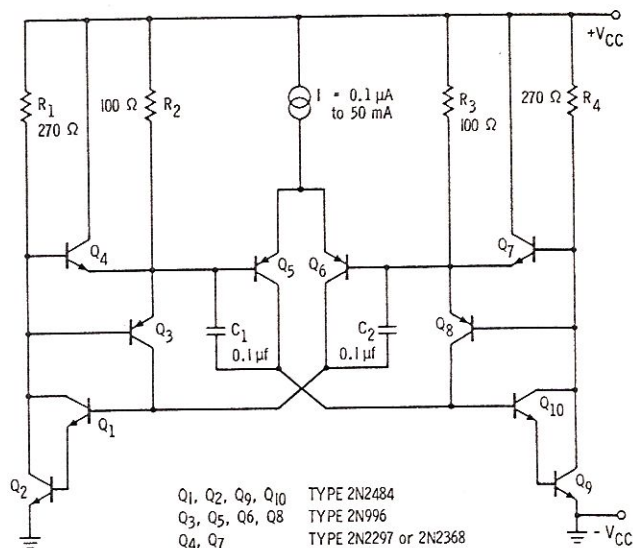


Fig. 1 Unique multivibrator with 2N2484's is variable from seconds to microseconds.

the charging-current switches, Q_5 and Q_6 . At room temperatures, 100 nanoamperes current is more than adequate for good symmetry when using silicon-planar transistors.

It appears from these relations that a high value of h_{FE} at very low collector current is required so that R_1 and R_4 can be made quite small for high frequency oscillation. The 2N2484 is such a transistor: for example, h_{FE} at 10 μA is 100 Min. and 500 Max. and h_{FE} at 500 μA is 200 Min. Darlington connected 2N2484's will give minimum Beta of 20,000 at 2 mA. The minimum value for R_1 and R_4 is given by the expression:

$$R_1 = V_{EB} 'on' (Q_3) / \beta (Q_1) \beta (Q_2) I_B (\text{min}) \\ \approx 0.5V / 2 \text{ mA} = 250 \Omega (R_1 = R_4).$$

Maximum R_2 and R_3 is given by the expression:

$$R_2 = R_1 \beta (Q_1, Q_2 Q_3) \approx 250 \times 1000 = 250K.$$

The maximum charging current for reliable linear operation is when C_1 and C_2 cannot be charged by Q_4 and Q_7 sufficiently to maintain linear current and time relationships. Therefore the maximum frequency of oscillation should be approximately five times the time constants of the recharge circuit or

$$5 [R_{EB} (Q_{10}, Q_9) \text{ av} + R_1 / \beta (Q_1)] C_1 \approx 7.5 \mu \text{sec} \\ \text{where } C_1 = 0.1 \mu \text{F}, R_1 = 250 \Omega, R_{EB} (Q_{10}, Q_9) \text{ av} \approx 10 \Omega.$$

The above limits are defined for the linear current-to-frequency range that can be expected for this circuit. By selecting $C_1 + C_2 = 0.1 \mu \text{F}$, a range of operation can be obtained from currents of $I = CE/t = 0.5 \times 10^{-6} / 10^{-5} = 50 \text{ mA}$ to the minimum recommended current of 100 nanoamperes, a range of 5×10^5 from 20 μsec periods to 10 secs.

* This material was prepared by J. A. MacIntosh, Applications Section, Fairchild Semiconductor.